ABSTRACT

Energy, Environment and Sustainable Development are intimately interconnected subjects attracting growing attention of researchers and policy makers in the modern world Increased economic activity calls for amplified energy consumption which in turn leads to more negative environmental implications thus challenging the Sustainable Development Hence, there is an "energy trilemma" involving interaction of energy use, sustainable economic development and environmental impact Although energy is a crucial input in all the sectors of an economy and a holistic analysis of above interaction is desirable, industrial sector deserves top priority because of its position as a dominant user of energy and its associated environmental implications Industrial sector of an economy comprises both large and small enterprises set up to meet various socio-economic objectives The Small Scale Industry (SSI) sector is of particular relevance to the developing world as it contributes significantly to employment generation, national income and exports Even if the amount of energy used by an individual SSI firm is trivial, the total energy consumption by the SSI sector as a whole assumes significant proportions in view of the large number of SSIs operating in economies, especially the developing ones

Among the developing countries, India has a unique place in promoting SSIs as it assigned a strategic role to this sector by introducing public policies and targeted efforts for their development However, after liberalization and increasing integration of national economy with global economy, the focus of SSI policy has been shifting from protection to promotion of this sector This has resulted in an unprecedented pressure on SSIs to enhance their competitiveness for survival and growth The literature pertaining to SSIs suggest that energy efficiency in SSIs is lower than that in their large scale counterparts Thus, improving energy efficiency, particularly in energy-intensive (with significant share of energy cost in total variable cost) SSIs, helps not only in enhancing their competitiveness through cost reduction but also aids in abatement of environmental pollution linked with energy use

Despite the literature pertaining to Indian SSIs confirming that their performance on energy and environmental front is far from satisfactory, often it goes unnoticed at the individual enterprise level due to insignificant quantum of energy use and its environmental

implications However, when these SSIs cluster in a geographical location, specifically energy-intensive ones, the quantum of total energy use and its associated environmental implications assume sizable proportions Further, such an industrial clustering in developing countries, including India, is significant and is also common in a wide range of sectors According to UNIDO, there are about 400 Small Industry Clusters and 2000 Rural & Artisan-based clusters in India Several of these clusters coming under Iron & Steel, Paper & Pulp, Cement, Textile, Brick & Tile, etc , are considered energy-intensive But, not many studies are found in literature dealing with energy consumption and its related issues in energy-intensive SSI clusters, prompting us to take up the present research work

A review of literature shows that though industrial sector share in total energy use differs across the countries of the world, it is one of the largest energy consuming sectors of almost every significantly industrialized economy For instance, industrial sector accounts for about 37% of the total national energy consumption in USA, around 30% in OECD countries and about 26% in the European Union At the global level, industrial sector is the largest energy consuming sector and accounts for about 32% of total energy consumption In most developing economies including India (with 43% share) the industrial sector accounts for highest share in total energy use amongst all the sectors The industrial sector of developing economies comprises a significant number of SSIs as well For instance, the small and medium scale industries put together constitute about 85% of the manufacturing establishments in major countries of Asia With a lion's share (about 95%) of total industrial units coming under SSIs in India, the energy consumption by the sector as a whole is likely to be substantial, though exact figures are not available However, SSIs have not succeeded in attracting researchers and policy makers in the past to the desired extent to study this vital issue Moreover, it is noticed that most of the initiatives to improve energy efficiency and environmental performance in SSIs have adopted mainly a technocratic approach and lacked a holistic perspective to comprehensively address the problem

On the whole, the review of available literature concerning energy related studies in Indian SSIs reveals the following

- ⊙ Most of the studies are either single cluster-based or single industry-focused and there is hardly any study of clusters comprising different regions of the country or involving diverse sub-sectors of the industry
- ⊙ The existing cluster-specific studies did not adopt scientific sampling techniques, required for generalizing the results to the cluster population
- ⊙ Though it is appropriate to analyze energy consumption within its social context, most of the energy studies in the past have ignored the influence of socio-economic context and the behavioural & organizational aspects of SSIs
- ⊙ There is also a dearth of studies probing the relationship of energy efficiency with environmental and economic performance in the clusters and its consequences
- ⊙ There is hardly any cluster-based study substantially dealing with barriers and drivers to energy efficiency improvement

The afore-said research gaps and subsequent discussion with the experts including academicians and the officials of Directorate of Industries & Commerce (DI&C), Government of Karnataka, and Technical and Consultancy Services Organization of Karnataka (TECSOK) helped us in formulating the objectives, scope and methodology of the present study Overall objective of the study is to ascertain the importance of energy as an input in the clusters and to demonstrate the linkages of energy efficiency with economic and environmental performance Further, it aims at analyzing the energy consumption in the SSI clusters by probing causes, consequences and constraints for energy efficiency so as to ultimately help the authorities in formulating policies related to energy efficiency improvement initiatives in this sector The specific objectives of the research are as follows

❶ To study the "energy consumption pattern" and associated "environmental pollution"

❷ To find out the current level of "energy efficiency" and estimate "energy conservation potential"

❸ To ascertain the "importance of energy in value of output" and probe the relationship between "energy efficiency" and "economic performance"

❹ To categorize and analyze the "factors influencing energy efficiency"

❺ To identify and prioritize the "barriers and drivers to energy efficiency improvement"

The study covers three energy-intensive (with significant share of energy cost in total variable cost) SSI clusters coming under three different "use-based industrial classification" in India, viz , basic goods (foundry), intermediate goods (brick & tile) and consumer goods (textile) The energy cost shares in Total Variable Cost (TVC) of these industries are about 15% in foundry and textile and around 40% in brick & tile The study clusters are incidentally located in the two South Indian States, Karnataka and Tamil Nadu While the foundry cluster of Belgaum and brick & tile cluster of Malur belonged to Karnataka, the third study cluster of textile is located in Tirupur of Tamil Nadu State Our study comprised iron foundries in Belgaum and both brick as well as tile producing firms in Malur However, in the Tirupur textile cluster we have included only textile dyeing firms as dyeing is the most energy-intensive process in the entire cycle of textile production Within each of the selected clusters a "random sampling design" is followed in picking SSI units, to enable wider generalization of study results to the respective clusters The study involves a total of 127 SSI enterprises (44 brick & tile firms, 42 iron foundries and 41 textile dyeing units)

At the outset, the study of energy consumption pattern revealed that biomass, coke, electricity and diesel are the main energy carriers used in the SSI clusters under reference While biomass accounts for almost the entire energy spent in brick & tile and textile dyeing clusters (shares of 99% and 96% respectively), coke dominates (79%) the total energy used in the iron foundry cluster From an end-use perspective, it is observed that in all the three clusters the thermal needs dictated the energy consumption The biomass, mainly in the form of eucalyptus leaves & twigs and firewood, provide the thermal energy needs of brick/tile baking in the kilns Firewood is the main fuel for boilers to generate steam required in the wet process of textile dyeing In the iron foundry cluster, coke serves as an energy source for metal melting in addition to providing the process energy required for endothermic chemical reaction of reducing pig iron

As far as environmental pollution connected with energy use is concerned, the study estimates air pollution in terms of Green House Gases (GHGs) and other pollutants as per the guidelines of Intergovernmental Panel on Climate Change (IPCC) The emissions of Carbon Dioxide (CO_2), Methane (CH_4), Sulphur Dioxide (SO_2), Nitrous Oxide (N_2O), Carbon Monoxide

(CO), Nitrogen Oxides (NO_X), Non Methane Volatile Organic Compounds (NMVOC) and Total Suspended Particulate matters (TSP) are estimated Initially, the emission intensities are computed in each cluster per unit of production and then it is extended to the entire cluster using average annual production volume Based on annual emission of CO_2, the main GHG, it is found that the textile dyeing cluster causes highest air pollution (about 616 kilo tonnes) followed by brick & tile (about 218 kilo tonnes) and iron foundry cluster (about 45 kilo tonnes) respectively In comparison, the annual emission of CO_2 in all the three SSI clusters put together is about 75% of emission from a typical Coal Thermal Power Plant of 210 MW capacity Thus, global pollution caused by individual SSI clusters may not be substantial, but their effect on local pollution merits attention However, in view of the existence of a large number of such SSI clusters in many other developing countries, the total effect of all such clusters on global pollution is likely to be significant

While the first objective dealt with present energy use pattern and its implications on environment, the second objective of the study is to assess the prevailing energy efficiency levels and subsequently to arrive at the energy conservation potential in the clusters In each cluster, we have estimated both the generally adopted micro and macro level energy efficiency indicators (Specific Energy Consumption (SEC) and Energy Intensity (EI) respectively) The average energy efficiency in terms of SEC (MJ/kg of product) in each of the clusters of brick & tile, iron foundry and textile dyeing is found to be 3 47, 5 87 and 39 24 respectively However, the efficiency expressed in terms of EI (MJ/Value added Rs) for these clusters are at 12 84, 0 96 and 1 96 respectively When efficiency is expressed in pure economic units in terms of Economic Energy Consumption (EEC) (Energy Rs /Value added Rs), the values for the cluster are found to be 0 54, 0 62 and 0 23 respectively The foregoing values bring out that lower SEC need not mean lower EI or lower EEC

Further, a wide variation in energy efficiency values observed among SSIs within each of the clusters point at the existing unrealized energy conservation potential Thus, we have analyzed how various aspects of firms including inputs, output and other performance parameters relate to energy consumption levels, by grouping the SSIs in each industry into – high, medium, and low – efficiency categories based on their energy efficiency levels by

(CO), Nitrogen Oxides (NO_X), Non Methane Volatile Organic Compounds (NMVOC) and Total Suspended Particulate matters (TSP) are estimated Initially, the emission intensities are computed in each cluster per unit of production and then it is extended to the entire cluster using average annual production volume Based on annual emission of CO_2, the main GHG, it is found that the textile dyeing cluster causes highest air pollution (about 616 kilo tonnes) followed by brick & tile (about 218 kilo tonnes) and iron foundry cluster (about 45 kilo tonnes) respectively In comparison, the annual emission of CO_2 in all the three SSI clusters put together is about 75% of emission from a typical Coal Thermal Power Plant of 210 MW capacity Thus, global pollution caused by individual SSI clusters may not be substantial, but their effect on local pollution merits attention However, in view of the existence of a large number of such SSI clusters in many other developing countries, the total effect of all such clusters on global pollution is likely to be significant

While the first objective dealt with present energy use pattern and its implications on environment, the second objective of the study is to assess the prevailing energy efficiency levels and subsequently to arrive at the energy conservation potential in the clusters In each cluster, we have estimated both the generally adopted micro and macro level energy efficiency indicators (Specific Energy Consumption (SEC) and Energy Intensity (EI) respectively) The average energy efficiency in terms of SEC (MJ/kg of product) in each of the clusters of brick & tile, iron foundry and textile dyeing is found to be 3 47, 5 87 and 39 24 respectively However, the efficiency expressed in terms of EI (MJ/Value added Rs) for these clusters are at 12 84, 0 96 and 1 96 respectively When efficiency is expressed in pure economic units in terms of Economic Energy Consumption (EEC) (Energy Rs /Value added Rs), the values for the cluster are found to be 0 54, 0 62 and 0 23 respectively The foregoing values bring out that lower SEC need not mean lower EI or lower EEC

Further, a wide variation in energy efficiency values observed among SSIs within each of the clusters point at the existing unrealized energy conservation potential Thus, we have analyzed how various aspects of firms including inputs, output and other performance parameters relate to energy consumption levels, by grouping the SSIs in each industry into – high, medium, and low – efficiency categories based on their energy efficiency levels by clustering them into three groups. Further, comparing the mean SEC values with the best among the sampled SSIs, an energy saving potential of about 35%, 46% and 60% is estimated in the brick & tile, iron foundry and textile dyeing clusters respectively. Even higher energy conservation potential exists in the clusters, if one considers the option of technology-shift in addition to other measures. In brick & tile industry, replacement of presently employed Intermittent Downdraught Kilns (IDK) with Vertical Shaft Brick Kilns (VSBK) is likely to save 75% of energy use. Similarly, adoption of Divided Blast Cupola (DBC) furnace instead of currently dominant conventional Cupolas in the iron foundry cluster would lead to an energy benefit of over 50% in metal melting. Likewise, in the textile dyeing cluster if all SSIs switch over to modern Soft Flow Machines (SFM) an energy conservation of more than the estimated 60% is realizable.

With the intention of ascertaining the importance of energy input in the value of output, we estimated the Cobb-Douglas production function in each of the three energy-intensive industries. The high values of adjusted R^2 (0.962, 0.981 and 0.929 in the brick & tile, iron foundry and textile dyeing respectively) of the estimated functions indicate their ability to explain most of the variations in the value of output with considered factors of production. Further, the significant beta coefficients of energy (0.641, 0.418 and 0.224 in the brick & tile, iron foundry and textile dyeing respectively) in each of the industries establish that energy is indeed an important input affecting value of output. While energy is found most important with highest beta coefficient amongst all the inputs in the brick & tile cluster, it ranked second only to material inputs in rest of the two clusters.

Then, to answer the question "Do energy-efficient SSIs also exhibit better economic performance?", we carried out correlation analysis between Economic Energy Consumption (EEC), which is a measure of energy efficiency and a host of economic performance indicators viz., factor productivities of labour and capital, joint productivity of labour & capital, gross value added, value added per value of output, capacity utilization, gross profit, and returns (ratio of gross profit to total cost). The result reveals significant correlation of energy efficiency with all the economic performance indicators in each of the SSI clusters. Strong associations are found between energy efficiency and joint productivity of labour and capital (-0 715, -0 697 and -0 743 for the brick & tile, iron foundry and textile dyeing respectively, negative sign owing to EEC being inverse of energy efficiency), value added per value of output (-0 891, -0 839 and -0 879 in the same order of clusters) and returns (-0 732, -0 791 and -0 786 in the identical order of clusters) Thus, results of our study indicate that enterprises performing well on the energy front are likely to exhibit better economic performance

Subsequently, we probed whether energy efficiency makes any significant difference to 'returns to scale', which indicates change in output relative to proportionate change in all the inputs including energy For this purpose, we classified SSIs within a cluster into "low energy efficiency" and "high energy efficiency" groups based on their EEC and then computed 'returns to scale' for both the groups separately The low efficiency groups are found with 'returns to scale' of 1 008, 1 017, and 0 939 respectively in the brick & tile, iron foundry and textile dyeing clusters, whereas the corresponding values in the high efficiency groups were 1 034, 1 023, and 1 011 respectively Thus, it is implied that in all the industries, the high efficiency groups enjoyed better 'returns to scale' than low efficiency groups Moreover, these differences in returns to scale are found statistically significant in all the three industries by the "Chow test" carried out in each case

Our fourth objective is to analyze the factors influencing energy efficiency in the SSI clusters Based on the limited literature available linking energy use with non-technology factors, we developed a hypothetical model of factors influencing energy efficiency in the SSI clusters encompassing Technical (TF), Economic (EF), Human Resource (HRF) and Organizational and Behavioural (OBF) factors Each factor level score is derived by cumulative sum of values of variables coming under the respective factor Subsequently, utilizing the scores of these hypothetical factors as independent variables and energy efficiency (SEC) as the dependent variable, multiple regression models are developed in each SSI cluster, thus attempting to explain the variation of energy efficiency (SEC) within a cluster by these four factors The result of regression analysis in the clusters indicates the significant ability of these factor-based models to explain variation in energy efficiency (R^2 of 0 87, 0 64 and 0 73 in the brick & tile, iron foundry and textile dyeing clusters respectively) The beta coefficients of the factors reveal that EF and OBF are (-0 35 EF, -0 32 OBF, -0 27 TF, and -0 22 HRF) the most influential factors of variations in energy efficiency in the brick & tile cluster However, the iron foundry cluster has only two factors in HRF and EF which are statistically significant and there is nothing much to choose between them (-0 43 HRF and - 042 EF), based on their beta coefficients In the textile dyeing cluster, beta coefficients of the factors (-0 57 HRF, -0 32 EF, and -0 19 TF) indicate the top position for HRF followed respectively by EF and TF in influencing the energy efficiency variation within the cluster The negative sign of these coefficients in all the three clusters indicates that the improvement in these factor levels lead to reduced SEC The difference in value of beta coefficient of a factor among the three clusters is mainly attributable to the dissimilarity in the products produced, production technologies adopted and socio-economic background

Going a step further, to identify the key variables under each factor and their possible interactions influencing energy efficiency, we carried out ANOVA analysis (sequential sum of squares method) with an *a priori* ordering of variables in each of the SSI clusters The ANOVA model in the brick & tile cluster fitted nicely with an adjusted R^2 of 0 91 to explain the variation in SEC It is found that the variables 'resource use efficiency', 'labour skill level', 'capacity utilization', 'importance attached to energy' and 'baking duration' are all significant in improving the SEC Besides, the interaction between 'resource use efficiency' and 'labour skill level' is also statistically significant in this cluster The ANOVA model developed for the iron foundry cluster has a moderate ability to explain the variation in SEC with adjusted R^2 of 0 54 Only two variables viz , 'labour skill level' and 'capacity utilization' are found statistically significant, without any significant interaction term, in explaining the SEC variation With respect to the textile dyeing cluster, the ANOVA has an adjusted R^2 of 0 72, which indicates a fair ability of the model to explain variation in SEC among the SSI firms in the cluster The analysis reveals that 'labour skill level', 'business experience of the owner' and 'plant capacity utilization' are the variables significantly influencing energy efficiency in this cluster, without any appreciable interaction among the variables even in this cluster The regression analyses as well as ANOVA have highlighted the significant role of non-technology factors in determining the energy efficiency level of a SSI firm in the clusters

The final objective of the study is to identify and prioritize the barriers and drivers to energy efficiency improvement with an intention of busting the former and boosting the latter Five barrier groups are considered in the study and their dimensions are recognized before ranking them based on four chosen criteria The barriers included in the analysis are related to Awareness and Information (AIB), Financial and Economic (FEB), Structural and Institutional (SIB), Policy and Regulatory (PRB) and Behavioural and Personal (BPB) aspects within SSI clusters The four criteria chosen for prioritizing the barriers in the SSI clusters are Intensity of Barrier (IOB), Easiness of Barrier Removal (EOBR), Impact of Barrier Removal on Energy Efficiency (IBREE) and Impact of Barrier Removal on Economic Performance (IBREP) For prioritizing these barrier groups in the SSI clusters, we have employed Analytic Hierarchy Process (AHP) which is a multi-criteria decision-making tool The required pair-wise comparison for the AHP analysis is derived based on the opinion and value judgment of SSI entrepreneurs obtained through a survey using a structured questionnaire The results of barrier ranking in all the three clusters based on composite weights of barrier groups within the clusters are identical though individual weights differed slightly Even though no barrier group obtained insignificant weight, FEB and BPB are found at the top two positions to be addressed for energy efficiency improvements in the SSI clusters

The six potential drivers of energy efficiency enhancement considered in the study included 'cost reduction', 'energy scarcity & price', 'environment protection', 'marketing label', 'government regulations' and 'enhancing competitiveness' Utilizing the entrepreneurial experience and value judgment, these drivers are prioritized Further, to obtain the relative strength of each driver, weighted average score is computed using normalized weights Again, the ranking of drivers reveals that the top two choices are identical in all the three SSI clusters 'Achieving cost reduction' and 'enhancing competitiveness' are the top two motivators for energy efficiency enhancement

Irrespective of the dissimilarities among the SSI clusters under reference in terms of socio-economic conditions, nature of product produced, geographical location, entrepreneurial background, raw material, energy carriers used etc , the top two barriers and drivers to energy efficiency enhancement remain the same This suggests that entrepreneurs in the SSI clusters encounter similar hurdles and are motivated by similar set of benefits associated with energy efficiency improvement Further, 'financial and economic barriers' followed by 'behavioural and personal barriers' are the prime hurdles, while 'achieving cost reduction' and 'enhancing competitiveness' are the top motivators of energy efficiency These two findings not only complement each other but also logically underscore the importance of previously identified non-technology factors which influenced energy efficiency within SSI clusters viz , HRF, EF and OBF Thus, there is a promising domain for a common set of policy interventions in SSI clusters, especially energy-intensive ones, to enhance the overall performance of SSIs

The policy initiatives to enhance energy efficiency in SSI clusters must necessarily recognize the role of non-technology factors While the prevailing thrust on technology up-gradation is undisputable, it is equally important to focus on economic, human resource, behavioural and organizational issues to produce discernible changes on the dual fronts of energy and environment, at the cluster level Enhancing the quality of human resource in SSIs by imparting specialized and periodic training to workers to improve their skill set and advanced managerial and technical training for the entrepreneurs to tackle complex issues like technology, energy efficiency, and environmental pollution, etc , is essential to produce better results in the long run SSI policy must also aim at improving capacity utilization in SSIs by increasing production volumes and in this regard marketing assistance for the goods produced by SSIs must be provided Prudent reduction in wastage of resources is to be encouraged through large scale implementation of Waste Minimization Circles (WMCs) and Quality/Environment Management Systems (QMS/EMS ISO 9000/ISO 14000) Industry Institute interaction has to be strengthened in this sector for mutual benefits Awareness and education programmes through consultancy, demonstration, workshops and seminars, etc , must be taken up in SSI clusters The local SSI associations and SSI development institutions must become more proactive and coordination among them must also be improved

The major contributions of this thesis are as follows

- The study covered three energy-intensive SSI clusters belonging not only to different industrial groups but also to diverse geographical locations

- A scientific sampling procedure is followed and hence the findings of the study are applicable for the entire population in the respective clusters
- The thesis analyzed current pattern of energy consumption and estimated the associated environmental implications in terms of air pollution Further, it compared the relative significance of this pollution with that of a typical Coal Thermal Power Plant
- The study has responded to the questions "Where do the clusters stand?" in terms of energy efficiency, and "How much of unrealized potential exists in these clusters?" based on the primary data obtained from the field
- The 'production functions' are estimated in each of the industries under study leading to appreciation of the role played by energy input in the value of output
- The positive association between energy efficiency and economic performance in the energy intensive SSIs is demonstrated through correlation analyses by considering a host of economic performance indicators
- The positive contribution of energy efficiency to enhance 'returns to scale' in the industries is ascertained
- A comprehensive theoretical model is put forward to analyze the factors influencing energy efficiency in the SSI clusters and is duly validated based on the empirical data pertaining to the three SSI clusters
- Using empirical data analysis it has been proved that it is necessary for the energy efficiency initiatives in SSI clusters to address economic, human resource, organizational and behavioural factors in addition to technical factors to bring about any appreciable change at the cluster level
- A quantitative approach is adopted to analyze barriers and drivers for energy efficiency enhancement
- A barrier analysis framework is proposed under a multi-criteria decision-making model and using AHP, the barriers are prioritized based on the value judgment of SSI owners, who are the main stakeholders of efficiency augmentation
- The potential drivers for energy efficiency improvement are identified and prioritized utilizing a weighted average scheme, again from an entrepreneurial perspective

We believe that this empirical study of energy consumption along with its associated issues in the three energy-intensive SSI clusters would be able to assist in triggering the concerned stakeholders to seriously consider energy efficiency improvement for the sustainable and long term growth of this sector The analysis of causes, consequences, constraints and motivators is likely to assist in fine-tuning the SSI policy in general and energy-intensive clusters in particular